Journal of Thermal Biology 49-50 (2015) 91–97

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Repeatability of a running heat tolerance test

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ARTICLE INFO

Article history:
Received 23 September 2014
Received in revised form
18 February 2015
Accepted 18 February 2015
Available online 19 February 2015

Keywords:
Heat tolerance
Continuum
Reliability
Thermoregulatory strain
Heat illness

ABSTRACT

At present there is no standardised heat tolerance test (HTT) procedure adopting a running mode of exercise. Current HTTs may misdiagnose a runner's susceptibility to a hyperthermic state due to differences in exercise intensity. The current study aimed to establish the repeatability of a practical running test to evaluate individual's ability to tolerate exercise heat stress. Sixteen (8M, 8F) participants performed the running HTT (RHTT) (30 min, 9 km h^{-1}, 2% elevation) on two separate occasions in a hot environment (40 °C and 40% relative humidity). There were no differences in peak rectal temperature (RHTT1: 38.82 ± 0.47 °C, RHTT2: 38.86 ± 0.49 °C, Intra-class correlation coefficient (ICC)=0.93, typical error of measure (TEM)=0.13 °C), peak skin temperature (RHTT1: 38.12 ± 0.45, RHTT2: 38.11 ± 0.45 °C, ICC=0.79, TEM=0.30 °C), peak heart rate (RHTT1: 182 ± 15 beats min^{-1}, RHTT2: 183 ± 15 beats min^{-1}, ICC=0.99, TEM=2 beats min^{-1}), nor sweat rate (1721 ± 675 g h^{-1}, 1716 ± 745 g h^{-1}, ICC=0.95, TEM=162 g h^{-1}) between RHTT1 and RHTT2 ($p > 0.05$). Results demonstrate good agreement, strong correlations and small differences between repeated trials, and the TEM values suggest low within-participant variability. The RHTT was effective in differentiating between individuals physiological responses; supporting a heat tolerance continuum. The findings suggest the RHTT is a repeatable measure of physiological strain in the heat and may be used to assess the effectiveness of acute and chronic heat alleviating procedures.

1. Introduction

During exercise in a hot environment, active muscles perform work causing an increase in body heat content. These changes are modulated by the rate of relative heat production (Cramer and Jay, 2014), and represent the rate of change in body heat storage, which in turn reflects the balance between metabolic heat production, heat absorbed from the environment and total body heat loss (Jay and Kenny, 2007). Individuals vary in their ability to withstand heat stress, with some demonstrating a decreased capability to dissipate heat and greater body heat content under the same exercise heat stress (Epstein, 1990). These individuals have been described as heat intolerant and are often characterized by an earlier and greater rise in body temperature, a greater storage of metabolic heat, a higher physiological strain to moderate intensity exercise in the heat and reduced sweating sensitivity (Epstein et al., 1983; Moran et al., 2004).

An individual's heat intolerant state may be temporary or permanent (Epstein, 1990; Moran et al., 2007; Ruell et al., 2014), stemming from transient predisposing factors, such as an acute injury to the thermoregulatory centre, insufficient heat acclimation, dehydration or infectious disease (Epstein, 1990). In addition, a lasting thermoregulatory dysfunction may stem from conditions such as cardiac disease, impairment to sweat glands (Epstein, 1990), or differences in gene expression (Moran et al., 2006). Congenital factors such as ectodermal dysplasia may also compromise heat tolerance in some individuals (Epstein, 1990). Aside from these predisposing factors, the high exercise intensity that endurance runners experience during competitions combined with extreme ambient conditions, may elicit unavoidable uncompensable heat production. The evaporative heat loss requirement to maintain a thermal steady state exceeds the maximal evaporative capacity of the individual in the given environment causing a continual rise in body temperature. The work by Nielsen (1996) provides data to suggest a marathon runner may experience up to a 1 °C rise every ~9 min when racing in high ambient conditions (35 °C, >60% relative humidity (RH)), when radiant and convective heat loss is negligible. This rate of rise in core temperature would result in the runner reaching a core body temperature of 40 °C within 25–30 min, with the immediate dangers of heat exhaustion. High incidences of exertional heat illness (EHI) have been reported in long distance runners, with 31% and 53% of the total cases of EHI during the 1992 New Orleans U.S. Olympic Trials and the 1996 Atlanta Olympics respectively,

Abbreviations: CV, Coefficient of Variation; EHI, Exertional Heat Illness; ICC, Intra-class Correlation Coefficient; IDF, Israeli Defence Force; LOA, Limits of Agreement; RHTT, Running Heat Tolerance Test; TEM, Typical Error of Measure

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http://dx.doi.org/10.1016/j.jtherbio.2015.02.010
0306-4565/

occurring in long distance runners (Martin, 1997). Whether heat intolerance is permanent or acquired the consequences of EHI among endurance athletes emphasise the importance of a running specific test to evaluate individual's ability to withstand exercise heat stress.

Experimental procedures have been applied to cause a rise in core temperature under resting and exercise conditions to challenge the thermoregulatory responses (Inoue et al., 2005; Johnson et al., 2013; Kenney and Hodgson, 1987; Montain et al., 1994). These procedures are used as a method of assessing the ability of an individual to withstand heat stress and evaluate heat dissipating mechanisms. The Israeli Defence Force (IDF) developed a heat tolerance test (HTT) to evaluate whether military personnel's experience of EHI, was temporary or permanent, supporting a safe return to duty (Moran et al., 2004). The protocol involves 120 min walking on a treadmill at a pace of 5 km h^{-1} and a 2% gradient in ambient conditions of 40 °C and 40% relative humidity (RH). Heat tolerance is determined at the end of the exposure, whereby peak rectal temperature (Tr_{peak}) $\leq$ 38.0 °C, peak heart rate (HR_{peak}) $\leq$ 120 beats min^{-1}, and sweat rate (SR) $\geq$ 780 g h^{-1}. Moran and colleagues (2007) acknowledge larger deviations from the specified criteria indicate a greater state of heat intolerance, whereas a pronounced plateau in both Tr and HR is a definitive sign of heat tolerance.

There is an instant elevation in the rate of thermogenesis at the onset of physical activity. As exercise intensity increases, especially in an uncompensable environment, a thermal imbalance persists. This results in a continually positive rate of change in body heat storage, increasing body heat content and a sustained rise in core temperature, giving a graded increase of heat strain (Jay and Kenny, 2007). The IDF HTT may be appropriate for specific occupational situations due to the low to moderate intensity coupled with the long exposure time that is likely to be experienced in military scenarios. Acknowledging the work carried out by the IDF, limitations associated with the HTT remain when examining endurance runners. EHI is compounded by uncompensable heat stress which is in turn influenced by the duration and intensity of exercise. The relative work intensity of an endurance runner training and competing in the heat is markedly higher compared with occupational activities. Therefore, the IDF HTT may not be applicable to an endurance population due to the duration and intensity of protocol. Nielsen, (1966) reported a 23% increase in heat production when running compared with walking on a 10% gradient at a matched energy production. Furthermore, a greater absolute exercise intensity has been shown to result in an increased heat production, irrespective of aerobic fitness (Jay et al., 2011; Mora-rodriguez et al., 2010). Consequently, the low intensity nature of current HTT may misrepresent the metabolic heat production of endurance runners and potentially misdiagnose their susceptibility to a hyperthermic state, pointing to the benefit of a running HTT (RHTT). At present there is no standardised HTT procedure adopting a running mode of exercise which may offer greater ecological validity to endurance runners.

Moran and colleagues (2004) assessed the heat tolerance of nineteen male participants and concluded that the duration of a HTT cannot be shorter than 120 min, since tolerance at 60 min was unable to predict tolerance at 120 min. The work by Epstein and colleagues (1983) and more recently by Moran and colleagues (2007) contradicts these findings, as the rate of increase in rectal temperature (Tr) and heart rate (HR) during the first 20–30 min was considerably different between those individuals deemed heat intolerant and those heat tolerant. This evidence suggests that it may be plausible to assess an individual's ability to withstand exercise heat stress in 30 min. A shorter RHTT requiring no prior testing would provide a more time efficient screening procedure for runners.

To assess and monitor changes in heat tolerance a protocol needs to reliable to minimise measurement error due to biological variation and equipment noise (Atkinson and Nevill, 1998). Typically, the assessment of reliability occurs on performance markers more often than physiological markers, and especially thermoregulatory markers. When the reliability of physiological markers has been assessed, it is often been between two pieces of equipment measuring the same physiological variable. Consequently, there is limited evidence comparing physiological markers during repeated trials using a set intensity exercise protocol. The reproducibility of mean aural temperature and mean heart rate during a fixed intensity cycling heat stress test, which involved three 20 min cycle bouts separated by 8 min rest was assessed in adolescents (Brokenshire et al., 2009). ICC of 0.58 and 0.95 for mean aural temperature and mean HR, respectively and a CV 0.1% and 3% for mean aural temperature and mean HR, respectively were reported and assumed indicative of strong measurement reproducibility. Determining the repeatability of physiological measures during a heat tolerance test would provide greater confidence in observed adjustment in heat tolerance following acute and chronic heat-alleviating interventions.

This study aimed to establish the repeatability of a practical running test to evaluate individual's heat tolerance. It was hypothesised that the RHTT would be repeatable, evidenced by small variations in physiological measures between repeated trials. The findings may enable specific guidance on preparation required prior to training or competing in high ambient conditions. These findings may also enable researchers and practitioners to use the RHTT to track accurately and interpret the changes in physiological variables resulting from acute and chronic interventions to alleviate heat strain in relation to the measurement error.

2. Materials and methods

2.1. Participants

Sixteen (8 males; 8 females) healthy individuals who typically perform a minimum of 9 miles per week within their weekly training, volunteered and provided written informed consent to participate in the current study (Mean $\pm$ SD, age 23 $\pm$ 5 years, body mass 67.07 $\pm$ 10.96 kg, height 1.76 $\pm$ 0.10 m, body surface area 1.82 $\pm$ 0.19 m^2, sum of four skin folds 43 $\pm$ 15 mm, speed at lactate threshold 11.7 $\pm$ 1.8 km h^{-1} and $\dot{V}O_2$ max 48.8 $\pm$ 6.5 ml kg^{-1} min^{-1}). The study was approved by the institution's ethics committee and conducted in accordance with the guidelines of the revised Declaration of Helsinki 2013.

2.2. Preliminary testing

During the first visit to the laboratory, anthropometric variables were measured, followed by a graded exercise test. Height and body mass were recorded using a stadiometer (Detecto, USA). Body surface area was calculated from the measurements of body mass and height (DuBois and DuBois, 1916). Sum of skin folds was determined from four sites (Durnin and Womersley, 1974); the bicep, triceps, subscapular and supra-iliac area using Harpenden skin fold callipers (Harpenden, UK). A graded exercise test was performed to determine participants lactate threshold and maximal aerobic capacity ($\dot{V}O_2$ max) using a motorised treadmill (PPS55 sport-1, Woodway, Germany), according to the British Association of Sport and Exercise Science Guidelines (Jones, 2007).

To determine the lactate threshold, participants performed five to nine, 3 min, incremental (0.8 km h^{-1}) stages on a treadmill. The initial running speed was set between 8 km h^{-1} and 10 km h^{-1}. On completion of the stage a capillary blood sample was taken